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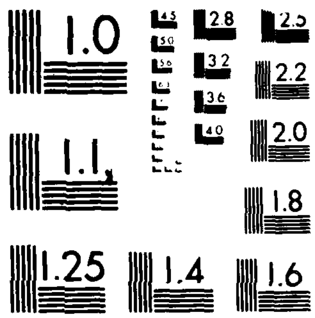

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RESEARCH ON NONLINEAR CONTROL THEORY

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ANNUAL SCIENTIFIC REPORT

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ABSTRACT

This annual report briefly describes progress on research in nonlinear control theory. Results reported include characterizations of the family of linearizations about constant operating points of nonlinear systems described by transform-domain Volterra series, explicit formulas for the linearization of an interconnected system in terms of subsystem linearizations, and a characterization for linearization by feedback. Publications describing these results in detail are listed.

1. RESEARCH OBJECTIVES AND STATUS

The objective of this research effort involves making use of recent developments in the representation and realization theories for nonlinear systems to address the problem of nonlinear feedback control. In particular, the objective is to characterize in explicit, input-output terms the relationships between open and closed-loop systems, and to use this characterization to develop more effective analysis and design techniques for nonlinear control systems.

Since the current, standard method for nonlinear system design is based on linearization of the nonlinear system equations, initial research toward the objective has focused on the relationship of a nonlinear system to its family of linearizations about a range of constant operating points. Using a transform-domain Volterra series representation for input-output behavior, a representation that appears to be suited to a wide range of flight control systems, explicit relationships have been developed for the parameterized transfer function that describes the family of linearizations. From these relationships, it is sometimes possible to describe simply the information about the nonlinear system embodied in the family of linearizations, or to see how certain structural characteristics of the nonlinear system can be ascertained from the form of the linearized transfer function. Also, it is easy to note various situations in which the linearization carries no useful information about the nonlinear system, so that design by linearization is doomed. For example, the linearization transfer function can be identically zero for non-trivial nonlinear systems. These results are reported in detail for discrete-time systems in [1], and for continuous-time systems in [2] and [3]. (These numbers refer to the publications listed in Section 2 of this report.)

A second step in the investigation was to develop the explicit relationship between the linearization of an interconnected nonlinear system and the subsystem linearizations, particularly for the feedback connection. While these relationships have been, in a vague sense, understood for some time, the explicit formulas obtained indicate more clearly the interaction between the operating point and the linearized system, i.e., how the linearized closed-loop system depends on the operating point. This is a key feature that limits the range of validity of a linearized design, since the linearization typically is accurate only in a neighborhood of a particular operating point. One interesting observation is that classical techniques of control system design that rely on the relationship between the linear open- and closed-loop systems must be used with great care in design-by-linearization settings. This is because the operating point value changes the relation of the open- and closed-loop systems. This work is reported in detail in [2].

The next step in this line of research is to use these results to propose better design methods than the standard design-by-linearization methods. To this end a promising method for extending the range of validity of linearized designs has been found, and this forms the basis for continuing work to be reported in due course.

Another line of research has involved relating the ideas described above to recent results by G. Meyer, R. Su, and L. R. Hunt on linearization by feedback, and its application to flight control. In this approach nonlinear feedback can be used, in certain cases, to achieve a linear closed-loop system, so that further design can be performed using linear-system methods. A characterization for linearization by feedback in terms of transform-domain Volterra series representations has been obtained, and is reported in [4].

Finally, some effort has been devoted to developing a nonlinear-system simulation capability in anticipation of the need to evaluate and verify proposed design methods. In the course of this effort, results for a recently proposed nonlinear control scheme for flight control at high angles of attack were verified, and in part corrected.

2. PUBLICATIONS

[1] R. Lejeune and W. J. Rugh, "Linearization of Discrete-Time Polynomial Systems About Constant Operating Points," Proceedings of the 17th Annual Conference on Information Sciences and Systems, The Johns Hopkins University, Baltimore, MD, pp. 422-426, 1983.

[2] W. J. Rugh, "Linearization About Constant Operating Points: An Input-Output Viewpoint," Proceedings of the 22nd IEEE Conference on Decision and Control, San Antonio, TX, pp. 1165-1169, 1983.

[3] R. Lejeune and W. J. Rugh, "Linearization of Nonlinear Systems About Constant Operating Points," IEEE Transactions on Automatic Control, accepted for publication, 1984.

[4] W. J. Rugh, "An Input-Output Characterization for Linearization by Feedback," Systems and Control Letters, accepted for publication, 1984.

3. PERSONNEL

Principal Investigator:

Wilson J. Rugh

Research Assistants (Graduate Students):

Roland Lejeune; BS, Ecole Centrale des Arts et Metiers, Belgium, MS, University of Virginia

William Baumann; BS, Lehigh University, MS, MIT

4. INTERACTIONS

The publications in Section 2 were presented as follows.

[1] was presented at the Conference on Information Sciences and Systems, Baltimore, MD, on 24 March 1983.

[2] was presented as an invited paper at the IEEE Conference on Decision and Control, San Antonio, TX, on 15 December 1983.

[3] was presented at a research seminar in the Department of Electrical Engineering, University of Maryland, College Park, MD, on 8 March 1983.

[4] will be presented at the Conference on Information Sciences and Systems, Princeton, NJ, on 14 March 1984.

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